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In most workplace environments we have encountered, clothed figures are the norm and would be expected by the designer. Adding clothing to a human figure improves its graphical appearance and realism. Clothes modeling can be done in many ways ranging from very simple to more realistic but complicated. The simplest technique is to change the attributes of certain segments of the body figure; for example, by modifying the colors of the lower legs we get the effect of a body wearing short pants. This is not quire as silly as it sounds, because the body segment geometry can be created with a clothed rather than bare-skinned shape. The best but more complicated approach is to drape and attach clothing over a body to simulate the intricate properties of garments.
Besides improving realism, there is a practical human factors aspect to clothing. Clothing constrains movement by restricting the joint angle limits. An approach to analyzing this problem has been developed by using collision detection for a geometric clothes model.

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# Modeling Clothed Figures
# Final Report: Army Grant DAAL03-90-G-0191

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# Clothing Models

**Abstract**

In most workplace environments we have encountered, clothed figures are the norm and would be expected by the designer. Adding clothing to a human figure improves its graphical appearance and realism. Clothes modeling can be done in many ways ranging from very simple to more realistic but complicated. The simplest technique is to change the attributes of certain segments of the body figure; for example, by modifying the colors of the lower legs we get the effect of a body wearing short pants. This is not quite as silly as it sounds, because the body segment geometry can be created with a clothed rather than bare-skinned shape. The best but more complicated approach is to drape and attach clothing over a body to simulate the intricate properties of garments.

Besides improving realism, there is a practical human factors aspect to clothing. Clothing constrains movement by restricting the joint angle limits. An approach to analyzing this problem has been developed by using collision detection for a geometric clothes model.

## 1 Geometric Modeling of Clothes

Rigid models for clothing are created by specially designing psurfs on a segment-by-segment basis. Thus a shirt or jacket would have, say, five parts: one for the torso, and two for each limb segment. Clothing exists independently of a given figure model as a library of objects which can be selectively placed on a model at user determined sites. This data base is modifiable through typical geometric editing commands. A clothing item is positioned by matching key points on the clothing to key points on the body segments. A global deformation algorithm can be used to fit the clothing piece correctly on the segment.

One apparent problem with geometrically modeled clothing occurs when the human figure moves joints. Since the clothing model is not deformable, there are gaps between segments. (This is in fact true even without clothing if the figure is modeled with polyhedral meshes. As the geometry is carried on the segment, it inherits the geometric transformation without any compensation for the interaction of material, flesh or clothes, at the joint.) Extra work is necessary to alleviate the joint gap problem. A gap filling algorithm has been developed to make up these gaps when animating. It connects the boundaries of two adjacent segments by generating spline surfaces using the tangent information of the two segments at the boundaries.

As an initial attempt to develop geometric models of clothes, a sweatshirt and pants were designed (Figure 1). Each segment of a clothing item is a psurf whose geometry and position are closely related to a corresponding body segment. The following is a step by step procedure for geometric clothes design.

1. Determine the size of clothes:

   In conventional clothing design, circumferences are measured at certain positions of the body in order to determine the clothing size. In our approach the maximum segment breadth in two orthogonal directions are measured instead of circumferences.

   The following list shows the positions at which the maximum breadths are measured and lists their corresponding slices from the accurate biostereometric slice bodies.

   - For trousers

     | | |
     |---|---|
     | waist | the 6th slice of lower_torso |
     | hip | the 9th slice of hip_flap |
     | upper leg | the first slice of upper_leg |

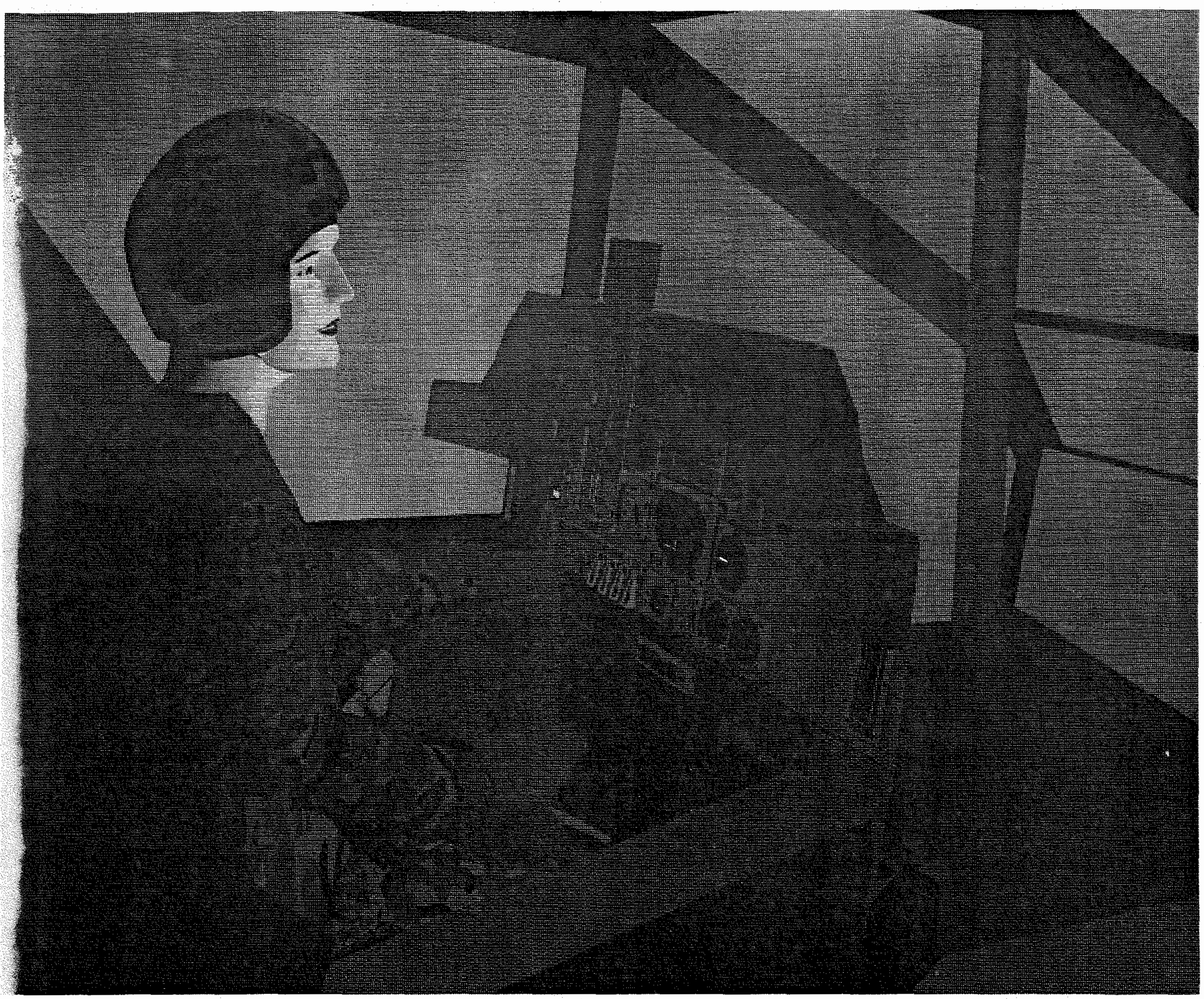

Figure 1: Texture-Mapped Camouflage Clothing on Contour Body Figure in Apache Helicopter Cockpit. Cockpit Courtesy NASA Ames Research Center. Image by Eunyoung Koh, Pei-Hwa Ho, and Jiahe Lu.

| | |
|---|---|
| lower leg | the last (24th) slice of lower_leg |

- For a sweatshirt

| | |
|---|---|
| neck | the first slice of upper_torso |
| chest | the 6th slice of upper_torso |
| breast | the 12th slice of upper_torso |
| waist | the first slice of lower_torso |
| upper arm | the 8th slice of upper_arm |
| lower arm | the last (16th) slice of lower_arm |

Also, a measure of the length from the neck to the bottom of the shirt is provided to determine the length of the shirt. These sizes are specified in advance for each article of clothing.

2. Create psurfs:
   The geometry of each segment is determined by a set of body slices. A new set of slices for clothing is constructed by sculpturing the body slices depending on the shape of the segment and the specified sizes in the previous step. The fundamental idea in the construction is to pick a few thick slices and duplicate them appropriately along the segment after scaling. Scaling is done by linear interpolation so that the scaled slices may match with the specified maximum breadth sizes at the positions designated.
   The completed surface definition of a clothes segment can be obtained by tiling the slices. Tiling is performed by generating rectangles from the data points which define two adjacent slices.
3. Attach clothes segments to human body:
   Each clothes segment can be attached to the corresponding body segment by a joint which is located at the upper part of that segment.

The clothing shape can be easily modified by changing the slice definition of the clothes. For example, folded sleeves, short sleeves, and short pants can be simulated by simple modification or deletion of slices.

# 2 Draping model

The most realistic clothing can be created by simulating the support and draping of pattern pieces of arbitrary shape. Wrinkling, folding, and the effects of gravity are displayed through a relaxation method or a finite element method. Pattern pieces may also be stitched at seams and draped simultaneously. Pattern pieces of different lengths may be sewn together, resulting in an oversewing effect.

The draping of the pattern pieces is done on a figure in a static posture. Interference testing is done in the draping algorithm to make sure that the pattern pieces slide over the surface of the figure without penetrating the surface (Figures 2).

There are several methods to simulate the draping of a square piece of cloth, isolated from other cloth, which are based on a relaxation method. Feynman [Fey86] uses a formula which minimizes the energy of a cloth and tries to simulate the shape of thin flexible membranes under the influence of force fields and rigid bodies. The local minimum of the cloth is found by moving each of the grid points in turn toward a position which decreases the energy of the cloth. The energy expression of a cloth is described as:

$$E_{total}(S) = k_s s(S) - k_b b(S) - k_g g(S)$$

where $s(S), b(S), g(S)$ represent the effects of strain, bending, and gravity. The parameters $\boldsymbol{k_s}, \boldsymbol{k_b}, \boldsymbol{k_g}$ control the relative strengths of these three effects: a large $\boldsymbol{k_s}$ means the cloth is difficult to stretch; a large $\boldsymbol{k_b}$ means the cloth is stiff and resists bending; and a large $\boldsymbol{k_g}$ means the cloth is heavy.

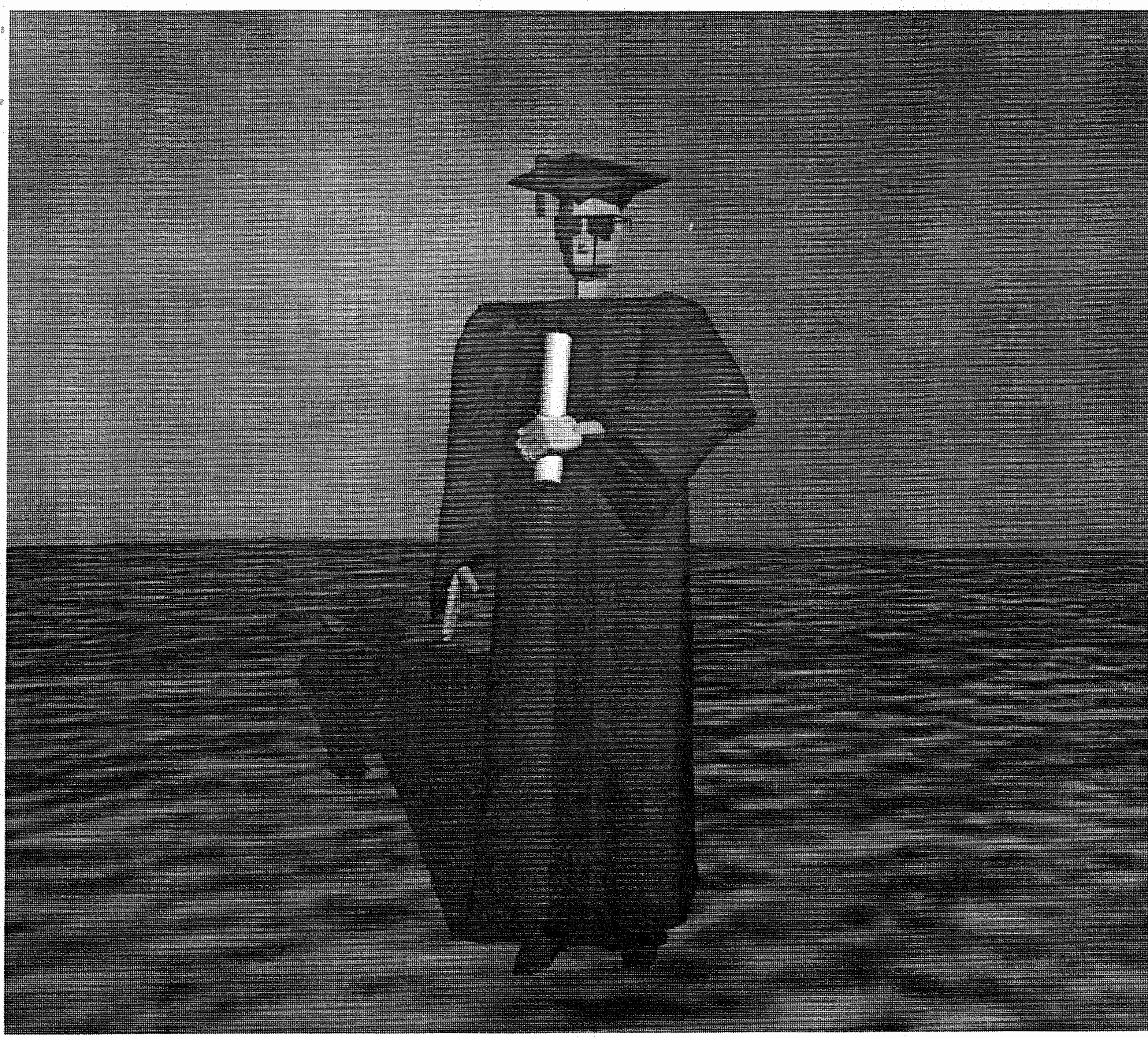

Figure 2: Graduation Day. Cloth modeling by Lauren Bello. Draping model by Welton Becket.

Relaxing a single point is the process of moving it so that the energy of the cloth of which it is a part is decreased. The method used to relax a single point first finds the direction in which the point would most like to move: the direction of the negative gradient of the energy as a function of position. Then it moves the single point in that direction so that its energy is minimized.

Feynman suggests using a multigrid method to speed up the relaxation sweeping process. However, it must be used carefully to avoid distortion. He also introduces fixed points in order to forbid the cloth to move into a solid.

Weil [Wei86] considered the problem of hanging a piece of cloth by fixing some constraint locations of the cloth. The cloth is represented as a rectangular grid $(u, v)$ of 3D coordinates $(x, y, z)$. His method is a two phase algorithm. The first part approximates the surface within the convex hull in $(u, v)$ space of the constraint points; that is, all the interior points are placed on catenaries. The second phase uses an iterative relaxation process to minimize maximum displacement of all the points in the grid up to a given tolerance.

The approximation process first positions the constraint points, then traces catenaries between each pair of constraint points, thereby positioning all grid points in such a catenary and creating triangles. If a point is in the path of two catenaries, it selects the highest point because it is a constraint that can't be violated (catenaries are the lowest possible points). All triangles created are subdivided by tracing catenaries from each vertex of the triangle to the midpoint of the opposite edge and creating two new triangles, that are recursively subdivided until all interior points have been positioned.

The relaxation phase tries to propagate the displacement of grid points until all maximum displacements fall below a certain tolerance. Determining the displacement of a point is done by obtaining the displacement vectors to position the point at the correct distance from each of its neighbors and adding the vectors. The final displacement is the square root of the sum of the squares of the displacements so that larger displacements will have more influence.

Terzopoulos, Platt, Barr and Fleisher [TPBF87] use elasticity theory to describe the behavior of a deformable object. The model responds in a natural way to applied forces, constraints, and impenetrable obstacles. The equations of motion governing the dynamics of the deformable bodies under the influence of applied forces is given

$$\frac{\partial}{\partial t}(\mu \frac{\partial r}{\partial t}) + \gamma \frac{\partial r}{\partial t} + \frac{\delta \mathcal{E}(\nabla)}{\delta \nabla} = f(r, t),$$

where $r(a, t)$ is the position of the particle $a$ at time $t$, $\mu(a)$ is the mass density of the body at $a$, $\gamma(a)$ is the damping density, and $f(r, t)$ represents the net externally applied forces. $\mathcal{E}(\nabla)$ is a functional which measures the net instantaneous potential energy of the elastic deformation of the body.

To create animation with this model, the motion equation is solved numerically, integrating through time. This model is active in the sense that it responds to forces and interacts with objects.

# 3 Computing Joint Limits

We tried to test the impact of clothing items on joint limits. A new joint limit affected by a clothing item is estimated by detecting collision among segments. Note that two adjacent segments will always give a collision. In order to solve this problem, we introduced a collision distance threshold: any nodes within the threshold from the joint position are ignored during collision detection.

We experimented with geometric models of an army vest and armor plate, by bending the left arm (left elbow joint) against the chest under three conditions: with the vest on, with armor plate attached, and with no clothes (Figure 3 and 4). The computed elbow joint limits were 78.5 deg, 96.0 deg, and 159 deg, respectively. Similar experiments with shirts of different thicknesses showed different effective joint limits of the left elbow joint when the figure tried to bend its arm.

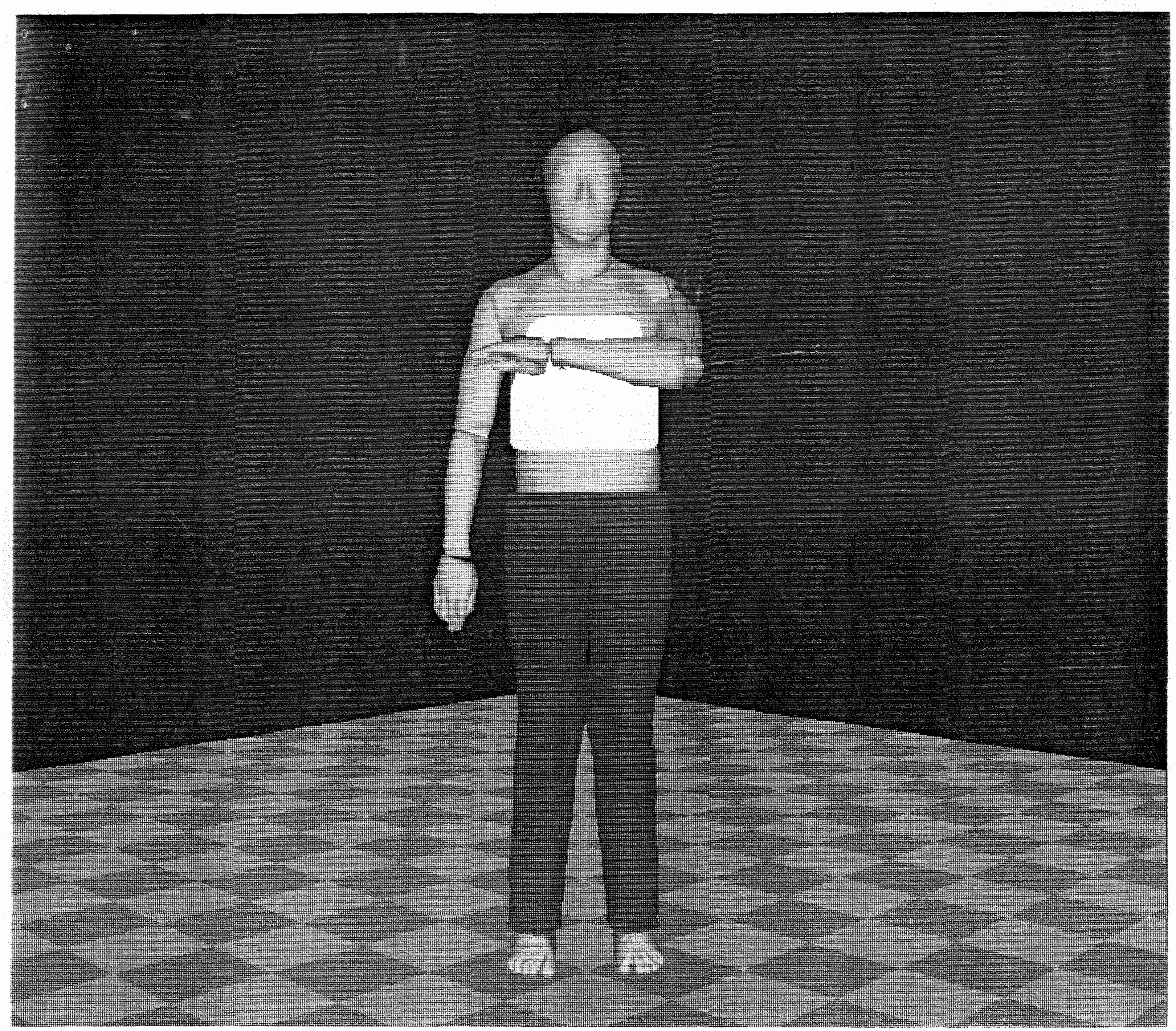

Figure 3: Army armor plate clothes for mobility experiments. Modeling by Eunyoung Koh.

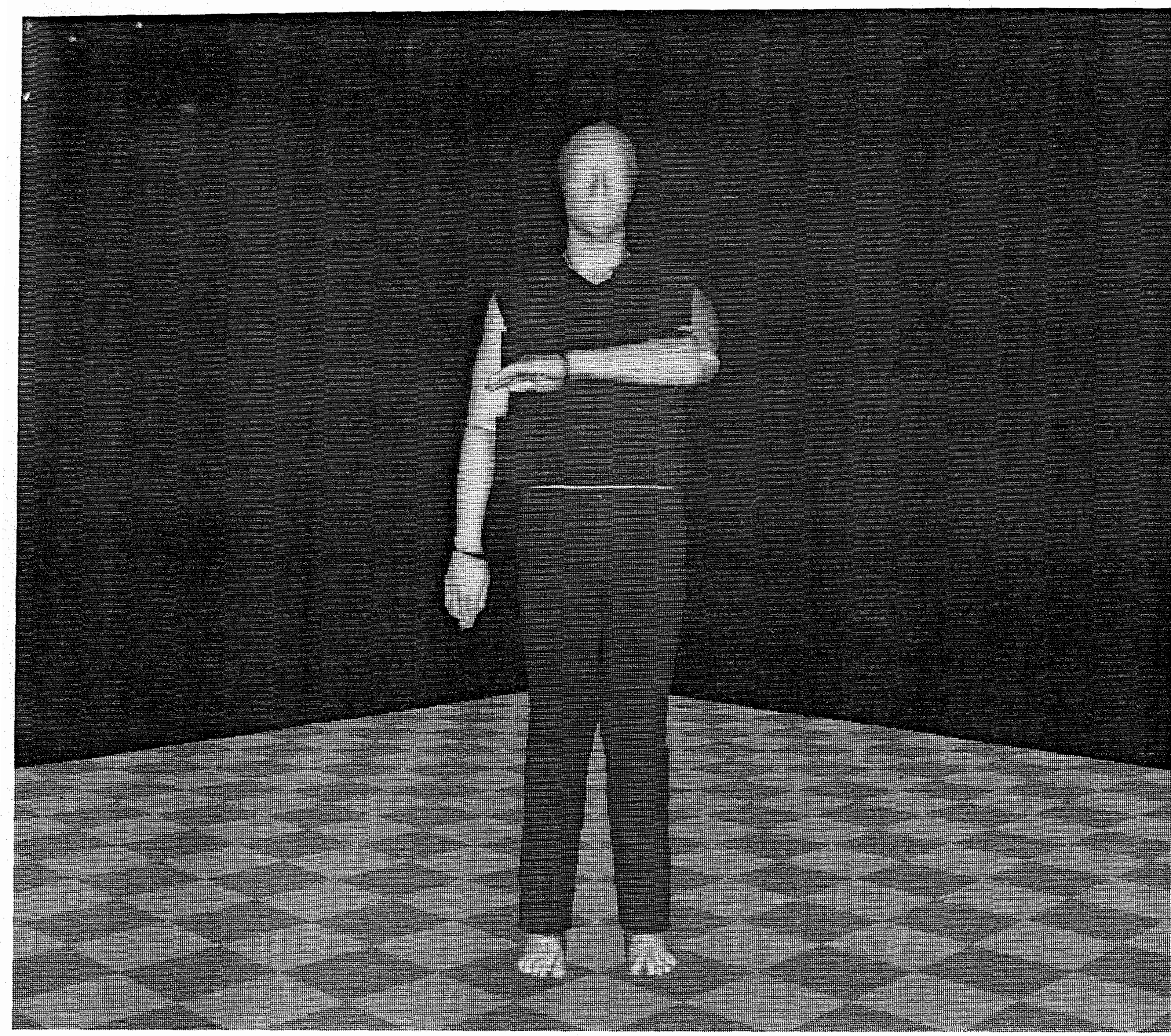

Figure 4: Army vest (with armor underneath) for mobility experiments. Modeling by Eunyoung Koh.

# 4 References

## References

[Fey86] Carl R. Feynman. Modeling the appearance of cloth. Master's thesis, Massachusetts Institute of Technology, 1986.

[TPBF87] Demetri Terzopoulos, John Platt, Alan Barr, and Kurt Fleischer. Elastically deformable models. In *Computer Graphics*, volume 21, pages 205–214, 1987.

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